Growth injury and morphological characteristics of mulberry under high temperature conditions

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An increase in global air temperature coinciding with an increase of atmospheric carbon dioxide concentration is predicted to occur in the future. In this study we investigated the effects of high temperature on temperate mulberry saplings by conducting 2 temperature (30°C and 35°C) treatments. Mulberry saplings grew normally at 30°C but were injured at 35°C wherein saplings developed malformed leaves. This injury appeared in the parts which grew during the treatment, but not in the parts which completed the growth before the treatment. The degree of injury depended on the developmental stage of each part at the beginning of the treatment. Leaves unfolding during the treatment became remarkably mosaic and malformed.

Key words: high temperature, heat injury, malformed leaves, mulberry tree

As a result of the rise in global atmospheric carbon dioxide and other “greenhouse gases” in the future, many climate models predict a significant increase in global temperature (STEPHEN, 1989). The effect of the rise on crop productivity is one of the most critical concerns in agricultural science. Although the response of plants to high temperature has been examined in various species (KAPPEN, 1981), most of the studies concentrated on a higher temperature than expected for a short period and such examinations applicable to the predictions have been reported only recently (BAKER et al., 1989, 1992). Regarding the mulberry (Morus genus), only a few reports were concerned with the response to high temperature (HAMADA, 1957), while the mulberry is an important cash crop in temperate regions where more than 70% of the cocoons in the world were produced in 1992. The objective of this study was to investigate the effect of high temperature for a long period on mulberry growing, and in this paper we deal with the growth injury induced by 35°C temperature treatment.

Materials and Methods

Control of environment in phytotrons: Two temperature treatment plots of 30°C and 35°C were designed using 2 glasshouse phytotrons, in which air temperature was controlled at 30 ±2.0°C and 35±2.0°C all day, with the saturation deficit kept below 10 hPa. In the phytotrons plants were exposed to natural
Fig. 1. Temporal trends in the shoot length (A) and in the number of unfolded leaves (B) for mulberry grown in 2 temperature regions. Each value represents the mean of all plants. Vertical bars represent ± SE.

Table 1. Temperature effects on morphological characteristics in 3 parts of shoots in 30°C and 35°C plots.

<table>
<thead>
<tr>
<th>Parts of shoot</th>
<th>Temperature (°C)</th>
<th>Leaf area (cm²)</th>
<th>Leaf length (cm)</th>
<th>Leaf width (cm)</th>
<th>Petiol length (cm)</th>
<th>Internode length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1 (Early unfolding)</td>
<td>30</td>
<td>127.56</td>
<td>14.67</td>
<td>12.09</td>
<td>2.95</td>
<td>2.88</td>
</tr>
<tr>
<td>Part 2 (Middle unfolding)</td>
<td>35</td>
<td>117.28</td>
<td>14.66</td>
<td>11.33</td>
<td>3.28</td>
<td>3.21</td>
</tr>
<tr>
<td>Part 3 (Late unfolding)</td>
<td>30</td>
<td>184.92</td>
<td>18.25</td>
<td>14.09</td>
<td>4.20</td>
<td>2.99</td>
</tr>
<tr>
<td>Part 3 (Late unfolding)</td>
<td>35</td>
<td>186.42</td>
<td>18.08</td>
<td>15.08</td>
<td>4.17</td>
<td>3.12</td>
</tr>
</tbody>
</table>

Parts of shoot were grouped according to the unfolding time. The time was decided by the degree of leaf deformation in the 35°C plot. Asterisks represent significant differences in the 30°C plot at the 0.01 level.

Fig. 2 (facing page). Top, mulberry that grew in a 35°C plot. Observed at the end of the temperature treatment. A, malformed leaves; B, light-green-spotted leaves; C, normally shaped leaves. Bottom, mulberry leaf unfolded in spring 1995 from a bud developed during 35°C treatment.
sunlight and watered by a drip-irrigation system. Air temperature and saturation deficit were measured by August wet- and dry-bulb thermometers at a height of about 1 m from the bottom of the phytotrons.

**Plant culture:** Mulberry grafting saplings (cv. Shin-ichinose) were planted in 1/5,000 a pots filled with volcanic ash soil on April 20, 1994, and were then grown outdoors until July 1. During this period, shoots were occasionally cut away so that each plant had one shoot. On July 1, 29 saplings were moved to each phytotron and were grown there for 62 days. The other 29 saplings remained outside as the untreated control. Each pot was fertilized with 0.8 g N, 0.32 g P2O5 and 0.32 g K2O at the time of planting and thereafter every 4 weeks.

**Measurement and plant sampling:** During the treatment, shoot length and the number of unfolded leaves for all plants were measured at intervals of about 15 days. At the end of the treatment, area, length and width of all leaves, as well as the length of all petioles and internodes, were measured for 3 plants in each plot. Other plants in the 35°C plot were moved outside to observe their growth in the spring of 1995.

**Results**

Fig. 1 shows temporal trends in the shoot length and the number of unfolded leaves in the 30°C and 35°C plots. In the 30°C plot the saplings grew normally during treatment, while in the 35°C plot the growth was injured gradually. Some light green spots appeared on leaves in the 35°C plot which unfolded within approximately 15 days from the beginning of the treatment, although leaf shape looked normal. Thereafter newly unfolded leaves in the 35°C plot became mosaic light green and malformed (Fig. 2, top), and after a while newly developed internodes and leaves became shorter and smaller, respectively. Finally, after the 45th day, shoot elongation and leaf unfolding gradually leveled off in most saplings (Fig. 1).

For the statistical analysis of shoot morphology in the 35°C plot, a shoot in the 35°C plot was divided into Part 1, 2 and 3 downside and compared with the corresponding parts in the 30°C plot. Part 1 includes 7 normally shaped leaves unfolding just before the treatment. Part 2 includes normally shaped but light-green-spotted leaves unfolding within 15 days from the beginning of the treatment. Part 3 includes malformed leaves unfolding between the 15th and 30th day. In Parts 1 and 2 no significant difference existed in all characteristics between the 30°C and 35°C plots, while in Part 3 the leaf area, length and width were significantly larger at a level of 0.01 in the 35°C plot (Table 1).

In the spring of 1995, most lateral buds of the plants grown in the 35°C plot sprouted and formed new shoots. The shoots in Part 1 were normal. However the shoots in Parts 2 and 3 developed malformed leaves similar to those in the previous year (Fig. 2, bottom).

**Discussion**

Growth injury appeared in temperate mulberry saplings that were grown under 35°C and high humidity conditions for a long period. This injury seems to be a physiological disorder caused by high temperature, since injury appeared only in Parts 2 and 3 which developed during the treatment and in the next spring malformed leaves unfolded from buds only in those parts. However, it is critical to regard 35°C as a lethal temperature for the temperate mulberry, because high temperature injury of plants depends also upon the duration of the exposed period (KAPPEN and
During this experiment, there were 3 successive days in which the outdoor temperature exceeded 35°C for a few hours. The plants in the untreated plot, however, showed no growth injury, and the best growth rate of shoot length in this period (data not shown). Moreover, in the 35°C plot, the leaves unfolding before the treatment showed no injury (Table 1). Thus it seems reasonable to conclude that the 35°C temperature had no harmful effects on the temperate mulberry to maintain existing organs, and that the 35°C exposure for a few hours was not critical.

As for the effect of temperature at a cellular level, we presume that the 35°C treatment for a long period has a harmful effect on cell division but encourages cell extension more than 30°C. This is because most growth points ceased in the 35°C plot probably due to cell division being suppressed, while leaf area, length and width in the 35°C plot were larger than in the 30°C plot in Parts 2 and 3 (although not significant in the former) perhaps due to cell extension being encouraged.

Concerning mulberry, there are only a few reports dealing with the growth dynamics of each organ (Ito, 1986; Fujita, 1986). We have encountered no papers dealing with cell division and extension during growth. Therefore, it is necessary to research mulberry morphologically as well as physiologically, in order to understand the mulberry growth response to high temperature.

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**References**


